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A Computer Program for Sample Size Computations for Banding Studies

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by

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Abstract

Sample sizes necessary for estimating survival rates of banded birds are derived based on specified levels of precision. The equations are derived for studies involving adults only, or adults and young, and the banding study can be new or ongoing. Precision is based on the desired coefficient of variation (CV) of the survival estimates. The CV for annual survival estimates, the CV for mean annual survival estimates, and the length of the study must be specified to compute sample sizes. A computer program, BAND2, has been written to compute the necessary sample sizes given the desired precision level and the length of the study. A description of the input and output for this program is provided.

Rationale

Data from migratory bird banding programs can be used to draw inferences about migration pathways and geographic distribution patterns. This data can also aid in estimating survival rate and, in conjunction with data from other sources, harvest rate, recruitment rate, and population size. These banding programs for migratory birds (and marking programs for many other vertebrates) often entail considerable effort and expense, thus making it important to plan these programs carefully. The investigator must first define study objectives explicitly. Then, the study design must ensure that objectives have a high probability of achievement. Banding the correct number (i.e., most efficient sample size) of birds is an important component of these studies, and here we present methods for calculating sample sizes for banding studies designed to estimate survival rates.

The band recovery models in Brownie et al. (1978, 1985; also see Seber 1970, 1982; Robson and Youngs 1971; Brownie and Robson 1976) have been used extensively during the last decade to estimate survival rates of hunted migratory bird populations, and, to a lesser extent, exploited populations of various fish and mammals. In the migratory bird studies, birds generally are banded at the same time (i.e., season; generally before the hunting season) and location(s) for each of several consecutive years. Each band is inscribed with a unique number permitting identifica-

tion of each banded individual. Banded birds are shot or found dead during the hunting season, and band numbers of some of these birds are reported to the bander or banding agency (e.g., the U.S. Fish and Wildlife Service Bird Banding Laboratory). The data resulting from banding operations of this type consist of the number of birds banded in each year of the study, and, from each banded sample, the number of band recoveries occurring in each subsequent hunting season included in the study.

In the general estimation approach employed by Brownie et al. (1985), these banding and recovery data are modeled as functions of two kinds of parameters: survival rates and band recovery rates. Survival rate is defined as the probability that a banded bird alive at the time of banding in year i is still alive at the time of banding in year $i+1$. Recovery rate is defined as the probability that a banded bird alive at the time of banding in year i is recovered (i.e., shot or found dead and the band reported to the Bird Banding Laboratory) during the hunting season of year i. The methods of Brownie et al. (1985) permit estimation of survival and recovery rates, and their associated sampling variances and covariances, under a variety of useful and realistic models. These models vary in their assumptions regarding the time and age specificity of the survival and recovery rates.

There are numerous important considerations when designing a banding study to estimate survival rate using band recovery models (Brownie et al. 1985:183–193). Some involve trying to insure that the banded sample is representative of the population about which inferences are to be drawn. Others involve attempts to insure that model assumptions are met, or, at least, that failures of the model assumptions are minimized (Brownie et al. 1985:6–7). Although these considerations are extremely important to the success of any banding study, they will not be addressed here.

In this paper, we restrict our attention to issues involving sample size; specifically, how many birds to band each year and how many years to band. To answer these questions the investigator must have some objective in mind. A statistic reflecting precision of the survival rate estimate seems a reasonable choice for such an objective. Here, we follow the approach of Brownie et al. (1985) and define the study objective by specifying the desired coefficient of variation (CV) of the survival estimate, $CV(\bar{S}) = (VAR(\bar{S}))^{1/2}/\bar{S}$, where $\bar{S}$ is the bias-adjusted survival rate estimate and VAR denotes sampling variance. The investigator may prefer to specify study objectives in terms of a desired $VAR(\bar{S})$ or approximate 95% confidence interval $[\bar{S}(1.00 \pm 1.96CV(\bar{S}))]$, and these are easily translated into a desired $CV(\bar{S})$. Guidelines and suggestions for choosing the $CV(\bar{S})$ have been outlined in Brownie et al. (1985:186–187).

The investigator must also specify the parameter of interest. For example, a study lasting k years will yield $k-1$ annual survival estimates, $\bar{S}_i$, and an arithmetic mean estimate of survival computed over the $k-1$ years. In some cases the investigator may be interested in annual estimates for one or more specified years of the study (see Youngs and Robson 1975). More frequently, the investigator will be interested in the average survival rate for the entire study (Brownie et al. 1985). The choice of the parameter of interest is important to sample size computations, as annual estimates require larger banded samples than mean annual estimates for a specific coefficient of variation.

We consider banded sample sizes both for new studies and for future years of studies currently under way. Methods to compute required banded sample sizes for new studies are shown in Brownie et al. (1985:186–193) and Youngs and Robson (1975), and an unpublished computer program has been written (Nichols and Hines 1979, unpub. memo.) to carry out the necessary computations. We receive many questions about sample sizes for new studies, and this program has proven very useful. However, we also receive many questions from investigators who are currently engaged in a banding study, but who either did not consider study objectives initially or have chosen to change study objectives. Even in cases where required sample sizes are determined initially, adaptive adjustment of future sample sizes is possible, and often desirable. The ease with which birds can be banded often varies from year to year, and realized banded sample sizes can vary substantially from target values. In addition, it may be found in the course of a banding study that realized survival and recovery rates may differ substantially from those anticipated, and on which initial sample size computations were based. Thus, there are many circumstances that might cause an investigator to ask how many birds to band in future years of a study currently under way. Some banding and recovery data are already available for studies under way, and sample size computations can be conditioned on these accumulated data.

In all of our sample size computations, we assume equal banded sample sizes for each year of banding in new studies, and for each future year of banding in ongoing studies. This approach is similar to that taken by Brownie et al. (1985) and Youngs and Robson (1975). We also assume the situation where the number of years of banding, k, equals the number of years of recovery, l. Again, this approach is similar to that taken by others and seems reasonable, because survival rates are only estimable through year $k-1$ and recovery rates are only estimable through

year k. Beyond these years, survival and recovery rates are only estimable as products such as $S_k f_{k+1}$, and these products are usually not of biological interest (Brownie et al. 1985:15).

To compute the banded sample size needed to yield a specified CV($\bar{S}$), it is necessary to specify a priori the true survival and band recovery rates that will operate during the study. Obviously, these true rates are not known. For new studies the investigator must supply these values, and they may be based on previous data or simply represent a best guess. For ongoing studies, the investigator may either use average survival and recovery rate estimates as computed from the previous years of the study or supply his best guesses. Our computational methods permit the investigator to supply different survival and recovery rates for each year of the projected study. In most cases there will be no basis for anticipating different year-specific survival and recovery rates, and it will be more reasonable to supply anticipated average rates and assume that they apply to all future years of the study. However, if a change in recovery or survival rates is anticipated in future years (e.g., because of a future change in hunting regulations) then it may be reasonable to use different year-specific survival and recovery rates in sample size computations.

The next several sections of this report—Notation, Sample Size Computations for Adult Birds, Sample Size Computations for Young Birds—provide derivations of the equations used to compute sample size needs. Readers not interested in these details should turn directly to the final section, Computer Program for Sample Size Computations.

Notation

The notation defined below is very similar to that of Robson and Youngs (1971), Youngs and Robson (1975), and Brownie et al. (1985).

S_i = annual survival rate for adult birds in year i,
S_i' = annual survival rate for young birds in year i,
$\bar{S}_i$ = bias-adjusted survival estimate of adults for year i,
$\bar{S}_i'$ = bias-adjusted survival estimate of young for year i,
f_i = recovery rate for adult birds in year i,
N_i = number of adult birds banded in year i,
N = recommended number of adult birds to band annually in future years,
M_i = number of young birds banded in year i,
M = recommended number of young birds to band annually in future years,
k = number of years of banding,
m = number of years of previous banding (and hence number of years of recoveries from previous banding years),
$\rho_i = f_i + S_i f_{i+1} + \ldots + S_i S_{i+1} \ldots S_{k-1} f_k$,
$\varepsilon_i = N_1 S_1 \ldots S_{i-1} + N_2 S_2 \ldots S_{i-1} + \ldots + N_i$,
$\varepsilon_i' = S_1 \ldots S_{i-1} + S_2 \ldots S_{i-1} + \ldots + 1$,
$d_i = N_1 S_1 \ldots S_{i-1} + N_2 S_2 \ldots S_{i-1} + \ldots + N_m S_m \ldots S_{i-1}$,
$h_i = S_{m+1} \ldots S_{i-1} + \ldots + 1$,
VAR($\cdot$) = the variance of the parameter ($\cdot$),
COV($\cdot,\cdot$) = the covariance of the two parameters ($\cdot,\cdot$),
CV($\cdot$) = coefficient of variation of the parameter ($\cdot$).

Note that we suspect that most investigators will use program BROWNIE and ESTIMATE to initially analyze their data, thus bias-adjusted survival estimates (e.g., $\bar{S}$) are used for our computations (Brownie et al. 1985:8,16).

Sample Size Computations for Adult Birds

New Studies

General Approach

All computations for adult birds are based on Model 1 of Brownie et al. (1985; also see Seber 1970; Robson and Youngs 1971). We prefer to base sample size computations on this general model, rather than on the more

restrictive Models 2 and 3 of Brownie et al. (1985) which require stronger assumptions and are less likely than Model 1 to be appropriate for any data set. Under this model, the variance of the survival estimate for year i ($\bar{S}_i$) can be written as:

$$\mathrm{VAR}(\bar{S}_i) = (\bar{S}_i)^2\left[\frac{1}{N_i}\left(\frac{1-p_i}{p_i}\right)+\frac{1}{N_{i+1}}\left(\frac{1-p_{i+1}}{p_{i+1}}\right)+\frac{f_i}{p_i(p_i-f_i)\varepsilon_i}\right], \text{ for } i = 1,\ldots,k-1. \tag{1}$$

The covariances of the adult survival estimates can be written as:

$$\mathrm{COV}(\bar{S}_i,\bar{S}_j) = \begin{cases} 0 & , j > i+1 \\ \dfrac{-(\bar{S}_i\bar{S}_j)}{N_j}\left(\dfrac{1-p_j}{p_j}\right) & , j = i+1,\ i = 1,\ \ldots,k-2. \end{cases} \tag{2}$$

For a new study the investigator must specify the number of years of banding (k) the anticipated survival (S_i) and recovery (f_i) rates, and the desired CV for the parameter of interest. Given this information, we write the CV of interest in terms of k, S_i, f_i, and annual banded sample size (N), and then solve the resulting expression for N.

Annual Survival Estimates

Estimates of specific annual survival rates for a particular level of precision can be obtained from the equation for the $\mathrm{CV}(\bar{S}_i)$:

$$\mathrm{CV}(\bar{S}_i) = \frac{\sqrt{\mathrm{VAR}(\bar{S}_i)}}{\bar{S}_i}. \tag{3}$$

Substituting for the right-hand side of equation 3 results in

$$\mathrm{CV}(\bar{S}_i) = \sqrt{\frac{1}{N_i}\left(\frac{1-p_i}{p_i}\right)+\frac{1}{N_{i+1}}\left(\frac{1-p_{i+1}}{p_{i+1}}\right)+\frac{f_i}{p_i(p_i-f_i)\varepsilon_i}}, \tag{4}$$

but for a new study we assume all $N_i = N$ and so equation 4 becomes

$$\mathrm{CV}(\bar{S}_i) = \sqrt{\frac{1}{N}\left(\frac{1-p_i}{p_i}+\frac{1-p_{i+1}}{p_{i+1}}+\frac{f_i}{p_i(p_i-f_i)\varepsilon_i'}\right)}. \tag{5}$$

Solving (5) for N results in

$$N = \left[\frac{1-p_i}{p_i}+\frac{1-p_{i+1}}{p_{i+1}}+\frac{f_i}{p_i(p_i-f_i)\varepsilon_i'}\right] / [\mathrm{CV}(\bar{S}_i)]^2. \tag{6}$$

Banding N birds for each of k consecutive years would then result in the desired $\mathrm{CV}(\bar{S}_i)$ assuming the guesses or estimates of S_i and f_i (usually assume $S_i = S$, and $f_i = f$ for all i) are reasonable.

Mean Annual Survival Estimates

Often, the average of the survival estimates over several years of a study is of interest; this average is referred to as the mean annual survival estimate ($\bar{\bar{S}}$). Again, the level of precision, $CV(\bar{\bar{S}})$, is specified and the following equation is used to solve for N:

$$VAR(\bar{\bar{S}}) = \left[\sum_{i=1}^{k-1} VAR(\hat{S}_i) + 2 \sum_{i=1}^{k-2} COV(\hat{S}_i, \hat{S}_{i+1}) \right] / (k-1)^2. \tag{7}$$

Dividing by $\bar{S}^2$ results in

$$[CV(\bar{\bar{S}})]^2 = \left[\sum_{i=1}^{k-1} VAR(\hat{S}_i) + 2 \sum_{i=1}^{k-2} COV(\hat{S}_i, \hat{S}_{i+1}) \right] / \bar{S}^2 (k-1)^2, \tag{8}$$

and, from equations 1, 2, and 8, the following equation results

$$[CV(\bar{\bar{S}})]^2 = \left\{ \sum_{i=1}^{k-1} (S_i)^2 \left(\frac{1}{N_i} \left(\frac{1-p_i}{p_i} \right) + \frac{1}{N_{i+1}} \left(\frac{1-p_{i+1}}{p_{i+1}} \right) + \frac{f_i}{p_i (p_i - f_i) \varepsilon_i} \right) \right.$$

$$\left. - 2 \sum_{i=1}^{k-2} \frac{S_i S_{i+1}}{N_{i+1}} \left(\frac{1-p_{i+1}}{p_{i+1}} \right) \right\} / \bar{S}^2 (k-1)^2. \tag{9}$$

Again we assume that $N_i = N$, and solving for N, the result is

$$N = \left[\sum_{i=1}^{k-1} (S_i)^2 \left(\frac{1-p_i}{p_i} + \frac{1-p_{i+1}}{p_{i+1}} + \frac{f_i}{p_i (p_i - f_i) \varepsilon_i} \right) - 2 \sum_{i=1}^{k-2} S_i S_{i+1} \left(\frac{1-p_{i+1}}{p_{i+1}} \right) \right] / [CV(\bar{\bar{S}})]^2 \bar{S}^2 (k-1)^2, \tag{10}$$

which also depends on the desired precision, the number of years in the study, and the anticipated survival and recovery rates.

Ongoing Studies

General Approach

In this situation, we consider an ongoing investigation for which m years of previous bandings and recoveries already exist. The object is to use the previous banding and recovery data to compute banded sample sizes (for the $k-m$ future years) necessary to achieve a certain level of precision of a survival estimate for one of these years. Computations are again based on Model 1 of Brownie et al. (1985; also see Seber 1970; Robson and Youngs 1971).

Annual Survival Estimates

If we take equation 4 and square both sides the result is

$$[CV(\hat{S}_i)]^2 = \frac{1}{N_i} \left(\frac{1-p_i}{p_i} \right) + \frac{1}{N_{i+1}} \left(\frac{1-p_{i+1}}{p_{i+1}} \right) + \frac{f_i}{p_i (p_i - f_i) \varepsilon_i}. \tag{11}$$

Now we solve for N when $i = m+1,\ldots,k$ and $N_i = N_{i+1} = N$ to get

$$[\mathrm{CV}(\bar{S}_i)]^2 = \frac{1}{N}\left(\frac{1-\rho_i}{\rho_i}\right) + \frac{1}{N}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right) + \frac{f_i}{\rho_i(\rho_i - f_i)(d_i + Nh_i)}, \tag{12}$$

where $\varepsilon_i = N_1 S_1 \ldots S_{i-1} + \ldots + N_i = d_i + Nh_i$, $d_i = N_1 S_1 \ldots S_{i-1} + \ldots + N_m S_m \ldots S_{i-1}$, and $h_i = S_{m+1} \ldots S_{i-1} + \ldots + 1$. This results in the following equation which can be solved for N using the quadratic formula:

$$h_i[\mathrm{CV}(\bar{S}_i)]^2 N^2 + \left[d_i[\mathrm{CV}(\bar{S}_i)]^2 - h_i\left(\frac{1-\rho_i}{\rho_i} + \frac{1-\rho_{i+1}}{\rho_{i+1}}\right) - \frac{f_i}{\rho_i(\rho_i - f_i)} \right] N - d_i\left(\frac{1-\rho_i}{\rho_i} + \frac{1-\rho_{i+1}}{\rho_{i+1}}\right) = 0. \tag{13}$$

The positive term of the quadratic becomes the correct solution for N, when $i = m+1,\ldots,k$.

Mean Annual Survival Estimates

If we are interested in the banded sample sizes for mean survival estimates ($\bar{\bar{S}}$) when previous banding exists for m years, we expand equation 9 to get

$$[\mathrm{CV}(\bar{\bar{S}})]^2 (k-1)^2 (\bar{S})^2 = \sum_{i=1}^{m-1} (S_i)^2 \left(\frac{1}{N_i}\left(\frac{1-\rho_i}{\rho_i}\right) + \frac{1}{N_{i+1}}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right) + \frac{f_i}{\rho_i(\rho_i - f_i)\varepsilon_i}\right)$$

$$+ (\bar{S})^2 \left(\frac{1}{N_m}\left(\frac{1-\rho_m}{\rho_m}\right) + \frac{1}{N}\left(\frac{1-\rho_{m+1}}{\rho_{m+1}}\right) + \frac{f_m}{\rho_m(\rho_m - f_m)\varepsilon_m}\right) - 2\sum_{i=1}^{m-1} \frac{S_i S_{i+1}}{N_{i+1}}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right)$$

$$+ \sum_{i=m+1}^{k-1} (\bar{S})^2 \left(\frac{1}{N}\left(\frac{1-\rho_i}{\rho_i}\right) + \frac{1}{N}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right) + \frac{f_i}{\rho_i(\rho_i - f_i)\varepsilon_i}\right) - 2\sum_{i=m}^{k-2} \frac{(\bar{S})^2}{N}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right). \tag{14}$$

This is equivalent to

$$[\mathrm{CV}(\bar{\bar{S}})]^2 (k-1)^2 (\bar{S})^2 - \sum_{i=1}^{m-1} \left((S_i)^2 \frac{1}{N_i}\left(\frac{1-\rho_i}{\rho_i}\right) + \frac{1}{N_{i+1}}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right) + \frac{f_i}{\rho_i(\rho_i - f_i)\varepsilon_i}\right)$$

$$- (\bar{S})^2 \left(\frac{1}{N_m}\left(\frac{1-\rho_m}{\rho_m}\right) + \frac{f_m}{\rho_m(\rho_m - f_m)\varepsilon_m}\right) + 2\sum_{i=1}^{m-1} \frac{S_i S_{i+1}}{N_{i+1}}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right)$$

$$= \frac{(\bar{S})^2}{N}\left(\frac{1-\rho_{m+1}}{\rho_{m+1}}\right) + \frac{(\bar{S})^2}{N}\sum_{i=m+1}^{k-1}\left[\frac{1-\rho_i}{\rho_i} + \frac{1-\rho_{i+1}}{\rho_{i+1}}\right]$$

$$- \frac{2(\bar{S})^2}{N}\sum_{i=m}^{k-2}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right) + (\bar{S})^2 \sum_{i=m+1}^{k-1}\left(\frac{f_i}{\rho_i(\rho_i - f_i)\varepsilon_i}\right), \tag{15}$$

where the last term can be written as (see equation 12)

$$(\bar{S})^2 \sum_{i=m+1}^{k-1} \left(\frac{f_i}{\rho_i(\rho_i - f_i)(d_i + Nh_i)} \right). \tag{16}$$

Equation 15 can be further reduced to get

$$[\mathrm{CV}(\bar{\bar{S}})]^2(k-1)^2(\bar{S})^2 - \sum_{i=1}^{m-1} (S_i)^2 \left(\frac{1}{N_i} \left(\frac{1-\rho_i}{\rho_i} \right) + \frac{1}{N_{i+1}} \left(\frac{1-\rho_{i+1}}{\rho_{i+1}} \right) + \frac{f_i}{\rho_i(\rho_i - f_i)\varepsilon_i} \right)$$

$$-(\bar{S})^2 \left(\frac{1}{N_m} \left(\frac{1-\rho_m}{\rho_m} \right) + \frac{f_m}{\rho_m(\rho_m - f_m)\varepsilon_m} \right) + 2 \sum_{i=1}^{m-1} \frac{S_i S_{i+1}}{N_{i+1}} \left(\frac{1-\rho_{i+1}}{\rho_{i+1}} \right)$$

$$= \frac{(\bar{S})^2}{N} \left(\frac{1-\rho_k}{\rho_k} \right) + (\bar{S})^2 \sum_{i=m+1}^{k-1} \left(\frac{f_i}{\rho_i(\rho_i - f_i)(d_i + Nh_i)} \right). \tag{17}$$

Equation 17 does not yield a closed form solution for N and an iterative solution must be obtained. We used the method of bisection to solve for N (Hamming 1971:36–42).

Sample Size Computations for Young Birds

New Studies

General Approach

The general model H_1 (Brownie and Robson 1976; Brownie et al. 1985) is assumed when computing sample sizes for young birds. Under this model adult and young birds must be banded each year, and precision of resulting survival estimates is a function of both adult and young banded sample sizes. As suggested by Brownie et al. (1985:190), we first compute the number of adults (N) to band under Model 1 to meet the specified precision criterion (see previous section), and then we use N to compute the number of young (M) to band. The precision of the adult survival estimate under Model 1 is very similar to that under H_1, and this fact allows the use of the adult sample sizes based on Model 1 survival estimates (Brownie et al. 1985:190). The computed adult banded sample size, N, along with k, S_i, S_i', and f_i are all used to compute M. Under model H_1 (Brownie and Robson 1976; Brownie et al. 1985) the variance of $\bar{S}_i'$ can be written as

$$\mathrm{VAR}(\bar{S}_i') = \frac{(\bar{S}_i')^2}{M_i} \left(\frac{1 - \bar{S}_i'\rho_{i+1}}{\bar{S}_i'\rho_{i+1}} \right) + \frac{(\bar{S}_i')^2}{N_{i+1}} \left(\frac{1-\rho_{i+1}}{\rho_{i+1}} \right), \tag{18}$$

and the coefficient of variation of $\bar{S}_i'$ as

$$\mathrm{CV}(\bar{S}_i') = \frac{\sqrt{\mathrm{VAR}(\bar{S}_i')}}{\bar{S}_i'}. \tag{19}$$

Annual First-year Survival Estimates

When we use the computed value of the corresponding adult sample size, N of equation 6, substitute equation 18 into 19, and assume $M_i = M$, we get:

$$[\mathrm{CV}(\hat{S}_i')]^2 = \frac{1}{M}\left(\frac{1-S_i'\rho_{i+1}}{S_i'\rho_{i+1}}\right) + \frac{1}{N}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right), \tag{20}$$

which leads to the following solution

$$M = \frac{1-S_i'\rho_{i+1}}{S_i'\rho_{i+1}} \Big/ \left[[\mathrm{CV}(\hat{S}_i')]^2 - \frac{1}{N}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right)\right]. \tag{21}$$

Mean Annual First-year Survival Estimates

The sampling covariance between annual first-year survival estimates is $\mathrm{COV}(\hat{S}_i'\,\hat{S}_j') = 0$, for $i \neq j$, $i = 1, \ldots, k-1$, so

$$\mathrm{VAR}(\bar{\hat{S}}') = \frac{1}{(k-1)^2}\sum_{i=1}^{k-1}\mathrm{VAR}(\hat{S}_i'), \tag{22}$$

and thus

$$[\mathrm{CV}(\bar{\hat{S}}')]^2 = \frac{\sum_{i=1}^{k-1}\mathrm{VAR}(\hat{S}_i')}{(k-1)^2(\bar{S}')^2}. \tag{23}$$

From equations 18 and 23, the following equation results

$$[\mathrm{CV}(\bar{\hat{S}}')]^2(k-1)^2(\bar{S}')^2 = \sum_{i=1}^{k-1}\left[\frac{(S_i')^2}{M}\left(\frac{1-S_i'\rho_{i+1}}{S_i'\rho_{i+1}}\right) + \frac{(S_i')^2}{N}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right)\right]. \tag{24}$$

Equation 24 can be solved for M to get

$$M = \frac{\sum_{i=1}^{k-1}(S_i')^2\left(\frac{1-S_i'\rho_{i+1}}{S_i'\rho_{i+1}}\right)}{[\mathrm{CV}(\bar{\hat{S}}')]^2(k-1)^2(\bar{S}')^2 - \sum_{i=1}^{k-1}\frac{(S_i')^2}{N}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right)}, \tag{25}$$

where N is computed from equation 10.

Ongoing Studies

General Approach

Again, Model H_1 of Brownie and Robson (1976) and Brownie et al. (1985) is used, but m years of previous banding data exist in the form of a recovery matrix, and the sample sizes of young for $k-m$ years are computed. As in new studies, the banded sample sizes for adults are computed first under Model 1, and then the sample sizes for young are computed.

Annual First-year Survival Estimates

As seen in equation 18, $\mathrm{VAR}(\bar{S}_i')$ depends entirely on data from bandings in years $\geq i$. Thus, the equation for computing the sample size for annual first-year survival estimates is the same as equation 21.

Mean Annual First-year Survival Estimates

Equation 24 can be further partitioned to get

$$[\mathrm{CV}(\bar{\bar{S}}')]^2(k-1)^2(\bar{S}')^2 = \sum_{i=1}^{m-1} \frac{(S_i')^2}{M_i}\left(\frac{1-S_i'\rho_{i+1}}{S_i'\rho_{i+1}}\right) + \sum_{i=m}^{k-1} \frac{(S_i')^2}{M}\left(\frac{1-S_i'\rho_{i+1}}{S_i'\rho_{i+1}}\right)$$

$$+ \sum_{i=1}^{m-1} \frac{(S_i')^2}{N_{i+1}}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right) + \sum_{i=m}^{k-1} \frac{(S_i')^2}{N}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right), \tag{26}$$

where N is from equation 17. Now, equation 26 can be solved for M and the result is

$$M = \sum_{i=m}^{k-1} S_i'\left(\frac{1-S_i'\rho_{i+1}}{\rho_{i+1}}\right) \Bigg/ \left\{[\mathrm{CV}(\bar{\bar{S}}')]^2(k-1)^2(\bar{S}')^2 - \sum_{i=1}^{m-1} \frac{S_i'}{M_i}\left(\frac{1-S_i'\rho_{i+1}}{\rho_{i+1}}\right)\right.$$

$$\left. - \sum_{i=1}^{m-1} \frac{(S_i')^2}{N_{i+1}}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right) - \sum_{i=m}^{k-1} \frac{(S_i')^2}{N}\left(\frac{1-\rho_{i+1}}{\rho_{i+1}}\right)\right\}. \tag{27}$$

Note that the denominators of equations 21, 25, and 27 can become negative for a small N or a small k. This means that for certain adult sample sizes, it becomes impossible to band enough young to achieve the specified level of precision. In these instances, several alternatives exist: (1) increase the CV for young, (2) increase the number of adults banded (N), or (3) increase the number of years of banding (k).

Computer Program for Sample Size Computations

Introduction

A user-friendly computer program has been developed to compute the sample sizes necessary to provide desired levels of precision for a banding study. The original program, BAND, was developed at the Patuxent Wildlife Research Center of the U.S. Fish and Wildlife Service in response to numerous requests for sample size guidelines for new banding studies. The current version, BAND2, was also developed at the Patuxent Wildlife Research Center, and includes the option of computing sample sizes for ongoing banding studies as well as new ones. The use of an IBM-PC, AT, or compatible computer is assumed in the following sections.

Interactive Input

Once started, the program will prompt the user for input. The input is free format (i.e., separated by commas or spaces), therefore, when several options are entered on a line, they should be separated by a comma or space. Program BAND2 will prompt for the input described below. Questions asked by BAND2 are in bold italics and options to choices are indicated by <IF> statements.

To start the program (assumed to be on the C drive) enter

C:>BAND2 (starts the program).

Note: To abort the program, type Ctrl-C at any prompt.

1. ***Output filename?*** (name of the output file, *cannot* be an existing file, LPT1, or CON)
2. ***Title?*** (any informative label up to 80 characters)
3. ***Number of years of proposed banding (4–50):*** (the number of years in the entire study [the numbers in parentheses indicate range of acceptable values])
4. ***Number of age classes (1 or 2):*** (1—adults only; 2—young and adults)
5. ***Enter ADULT annual and mean % coef. of var. (CV) (in %):*** (the desired precision level for adults, expressed as the percent coefficient of variation of the survival estimates; two rates must be entered)
6. <IF NUMBER OF AGE CLASSES = 2>***Enter YOUNG annual and mean % coef. of var. (CV) (in %):*** (the desired precision level for young, expressed as the percent coefficient of variation of the survival estimates; two rates must be entered)
7. <IF NUMBER OF AGE CLASSES = 2>***Adult population size increment (e.g., 1000)?*** (used to increase adult sample size if computations for young are not possible at specified precision [see page 9, fourth paragraph, for a further explanation])
8. ***Do you wish to input previous banding data (y or n)?:*** (Y—ongoing study with previous recoveries; N—new study)

BEGIN SECTION FOR <IF PREVIOUS BANDING DATA = N>

9. ***Are all anticipated surv. & recv. rates constant over time (y or n)?*** (Y—proposed years of banding have the same survival and recovery rates; N—user will input survival and recovery rates for each year)
10. <IF RATES CONSTANT = Y>***Enter adult survival rate:***
11. <IF RATES CONSTANT = Y AND AGE CLASSES = 2>***Enter young survival rate:***
12. <IF RATES CONSTANT = N>***Enter* n−*1 adult survival rates:***
13. <IF RATES CONSTANT = N AND AGE CLASSES = 2>***Enter* n−*1 young survival rates:***
14. <IF RATES CONSTANT = Y>***Enter adult recovery rate:***
15. <IF RATES CONSTANT = N>***Enter* n *adult recovery rates:***

END OF SECTION FOR <IF PREVIOUS BANDING DATA = N>

BEGIN SECTION FOR <IF PREVIOUS BANDING DATA = Y>

16. ***Is a recovery matrix to be read from disk (y or n)?*** (previous recoveries can be entered in the form of a recovery matrix and the program will compute survival and recovery estimates from the data versus entering the survival and recovery estimates directly; the format for the file is described later)
17. <IF RECOVERY MATRIX = Y>***Enter filename for input of recovery matrix:*** (file with recovery data from previous banding study)
18. <IF RECOVERY MATRIX = N>***Enter # of years of previous banding (*m *= 2–30):*** (the *m* years for which bandings and recoveries already exist from the ongoing study)
19. <IF RECOVERY MATRIX = N>***Enter* m−*1 adult survival rate estimates:***
20. <IF RECOVERY MATRIX = N>***Enter* m *adult recovery rate estimates:***
21. <IF RECOVERY MATRIX = N>***Enter the number of adults banded for each of the* m *years:***
22. <IF RECOVERY MATRIX = N AND AGE CLASSES = 2>***Enter* m−*1 young survival rate estimates:***

23. <IF RECOVERY MATRIX = N AND AGE CLASSES = 2>***Enter the number of young banded for each of the* m *years:***
24. ***Do you want average anticipated future survival rates estimated from the previous banding data (y or n):*** (Y—the program will compute the average of the survival rates from the input data and use these averages in computations for future years; N—user will input anticipated survival rates for computations in future years)
25. <IF AVERAGE SURVIVAL ESTIMATED FROM PREVIOUS DATA = N>***Enter 1 to input constant surv. rate for adults & young, enter 2 to input* n *survival rates (1 or 2):*** (if the survival rate for adults and young will be assumed constant for the *n* years of proposed banding enter 1; entering a 2 will prompt for *n* survival rates for adults and *n* survival rates for young)
26. >IF AVERAGE SURVIVAL ESTIMATED FROM PREVIOUS DATA = N AND QUESTION 24 ABOVE = 1>***Enter adult survival rate:***
27. <IF AVERAGE SURVIVAL ESTIMATED FROM PREVIOUS DATA = N AND QUESTION 24 ABOVE = 1 AND AGE CLASSES = 2>***Enter young survival rate:***
28. <IF AVERAGE SURVIVAL ESTIMATED FROM PREVIOUS DATA = N AND QUESTION 24 ABOVE = 2>***Enter* n *adult survival rates:***
29. <IF AVERAGE SURVIVAL ESTIMATED FROM PREVIOUS DATA = N AND QUESTION 24 ABOVE = 2 AND AGE CLASSES = 2>***Enter* n *young survival rates:***
30. ***Do you want the average anticipated future adult recovery rate estimated from the previous banding data (y or n):*** (Y—the program will compute the average of the recovery rates from the input data and use the average in computations for future years; N—user will input anticipated recovery rates for computation in future years)
31. <IF AVERAGE RECOVERY ESTIMATED FROM PREVIOUS DATA = N>***Enter 1 to input a constant recovery rate for adults, enter 2 to input* n *recovery rates (1 or 2):*** (if the recovery rate for adults will be equal for the *n* years of proposed banding enter 1; entering a 2 will prompt you for *n* recovery rates for adults)
32. <IF AVERAGE RECOVERY ESTIMATED FROM PREVIOUS DATA = N AND QUESTION 30 ABOVE = 1>***Enter adult recovery rate:*** (one number)
33. <IF AVERAGE RECOVERY ESTIMATED FROM PREVIOUS DATA = N AND QUESTION 30 ABOVE = 2>***Enter* n *adult recovery rates:***

END OF SECTION FOR <IF PREVIOUS BANDING DATA = Y>

Batch Input

As an alternative to interactive input, the user can create an input file with responses in the same order as in the interactive mode and begin BAND2 in batch mode. The input file can be created by using an ASCII editor (such as EDLIN, available with MS-DOS) or a word processor that can create an ASCII file. Once the ASCII input file is created the program can be executed by entering the following statement at the operating system prompt:

BAND2<INPUT.DAT

The program will then execute without prompting the user. An example of inputs for batch mode is given below: The input file might be called "page58.inp" (i.e., the data can be found on page 58 in Brownie et al. [1985]).

```
page58.out
Sample sizes for 5 additional yrs of banding based on pg 58 Brownie et al. 1985
5
2
13,3
13,4.5
1000
y
y
page58.dat
y
y
```

In addition to this data, the recovery matrix must be located in a file called "page58.dat." Although the format of the recovery matrix is similar to the form described in Brownie et al. (1985:155–157), the file must be in free format. The recovery matrix file is described below:

line1: heading information (maximum of 80 characters)
line2: the number of years of banding (k), the number of years of recovery (l), the first year of the banding study, and a numeric code (any single-digit integer) [the number of years of banding and recovery should be equal for program BAND2]
line3: the next lines are for the array of adult recovery numbers; if there are k years of banding then there should be k lines beginning at **line3** (if the recovery matrix is longer than 80 columns, the lines can be continued past column 80 or on the next line)
next line: the number of adult birds banded in each year (N_i)

If young were also banded, the following lines would be included:

next line: the next lines are for the array of young recovery numbers; if there are k years of banding then there should be k lines beginning at **line3**
next line: the number of young birds banded in each year (M_i)

As an example, the data from page 58 of Brownie et al. (1985), which would be in a data file called "page58.dat," would look like the following:

```
Adults and Young banded, San Luis Valley, CO 1963-1971
9,9,1963,1
10,13,6,1,1,3,1,2,0
58,21,16,15,13,6,1,1
54,39,23,18,11,10,6
44,21,22,9,9,3
55,39,23,11,12
66,46,29,18
101,59,30
97,22
21
231,649,885,590,943,1077,1250,938,312
83,35,18,16,6,8,5,3,1
103,21,13,11,8,6,6,0
82,36,26,24,15,18,4
153,39,22,21,16,8
109,38,31,15,1
113,64,29,22
124,45,22
95,25
38
962,702,1132,1201,1199,1155,1131,906,353
```

If only adults were being analyzed, the last 10 lines could be deleted, but this is not necessary because the program would only read the first 12 lines when computing adults only. The above data file could have been created with spaces instead of commas. This means that most data files created using the format of Brownie et al. (1985:155–157) will work with minor adjustments. For example, the last line could also have been written as:

```
962 702 1132 1201 1199 1155 1131 906 353
```

Detailed Examples of Program Input and Output

Program BAND2 will produce heading information, the number of years of proposed banding, the desired annual and mean annual coefficients of variation (CV), and the required number of banded birds. If it is impossible to band enough birds to achieve the desired mean annual CV, then a message will be printed along with the minimum possible CV. In addition, if the desired mean annual CV was not achievable for banded young, then the program will compute possible combinations of adults and young that would achieve the desired CV. If the number of young computed is greater than 10,000, the program will also compute additional combinations with larger numbers of banded adults.

In each of the following examples, the input file is given as well as the computer output. The program could be run in interactive mode by using each line of the input file below as an answer to the program questions, or by using the input file in batch mode. Some of the example input files are included with program BAND2 when it is distributed. The input portion is in bold italics.

Example 1: A new 5-year banding study on adult male mallards (*Anas platyrhynchos*) is to begin, and a CV of 10% for annual survival and a CV of 3% for mean annual survival are desired. From reliable sources, the anticipated survival and recovery rates are approximately 0.6 and 0.075, respectively. The input file is as follows:

Input file	Remarks
exampl.out	Output data file name
Mallard Study, example 1	Title
7	7 years of banding
1	One age-class
10,3	Annual CV = 10%; mean CV = 3%
n	N = no previous banding data
y	Y = yes, all anticipated survival and recovery rates are equal
.6	Survival rate = 0.6
.075	Recovery rate = 0.075

and the output is as follows:

Program BAND2—Sample Size Computations for Banding
Studies Patuxent Wildl. Res. Center, USFWS, 5/25/1989

Mallard Study, example 1
7 YEARS BANDING, ADULT—CV(ANNUAL SURVIVAL) = 10.0%, CV(MEAN SURVIVAL) = 3.0%

YEAR	SURV RATE	RECV RATE	% CV	REQUIRED BANDS
1	0.6000	0.0750	10.0	1292.
2	0.6000	0.0750	10.0	1190.
3	0.6000	0.0750	10.0	1217.
4	0.6000	0.0750	10.0	1332.
5	0.5000	0.0750	10.0	1621.
6	0.6000	0.0750	10.0	2549.
MEAN	0.6000	0.0750	3.0	1134.

To achieve a mean annual CV of 3%, the investigator should band 1,134 adult birds for each of the 7 years. If the investigator wants to achieve an annual CV of 10% in year 4, he should band 1,332 adult birds for each of the 7 years. To assure an annual CV of 10% for all years, the investigator should band the largest suggested number, 2,549.

Example 2: In this example, we hypothesize that a change in hunting regulations will occur after the first 3 years of a 6-year study on Canada geese (*Branta canadensis*) such that $S = 0.75$, $S' = 0.65$, and $f = 0.06$ for years 1–3, and $S = 0.7$, $S' = 0.6$, and $f = 0.12$ for years 4–6. The desired levels of precision for the annual and mean

survival estimates expressed as percent CV are 12 and 4, respectively, for both adults and young. The input would be as follows:

Input file	Remarks
examp2.out	Output data file name
Adult and Young Canada Goose Study, example 2	Title
6	6 years of banding
2	Two age-classes
12,4	Adult annual CV = 12%; mean CV = 4%
12,4	Young annual CV = 12%; mean CV = 4%
750	Adult population increment = 750
n	N = no previous banding data
n	N = no, anticipated survival and recovery rates not constant
.75 .75 .75 .7 .7	Five anticipated adult survival rates
.65 .65 .65 .6 .6	Five anticipated young survival rates
.06 .06 .06 .12 .12 .12	Six anticipated adult recovery rates

and the output is as follows:

Program BAND2—Sample Size Computations for Banding Studies
Patuxent Wildl. Res. Center, USFWS, 5/24/1989

Adult and Young Canada Goose Study, example 2
6 YEARS BANDING, ADULT—CV(ANNUAL SURVIVAL) = 12.0% CV(MEAN SURVIVAL) = 4.0%
YOUNG—CV(ANNUAL SURVIVAL) = 12.0% CV(MEAN SURVIVAL) = 4.0%

	ADULT		YOUNG			
YEAR	SURV RATE	RECV RATE	SURV RATE	% CV	REQUIRED ADLT BNDS	REQUIRED YNG BNDS
1	0.7500	0.0600	0.6500	12.0	502.	597.
2	0.7500	0.0600	0.6500	12.0	455.	619.
3	0.7500	0.0600	0.6500	12.0	431.	615.
4	0.7000	0.1200	0.6000	12.0	547.	987.
5	0.7000	0.1200	0.6000	12.0	947.	1936.
MEAN	0.7300	0.0900	0.6300	4.0	396.	

4.0% CV NOT POSSIBLE FOR YOUNG
WITH ONLY 396. ADULTS
SMALLEST POSSIBLE CV(YOUNG) FOR 396. ADULTS = 4.43%
SMALLEST POSSIBLE CV ASSUMES AN INFINITE NUMBER OF YOUNG ARE BANDED

POSSIBLE COMBINATIONS OF ADULTS & YOUNG WITH CV = 4.0% & 4.0%, RESPECTIVELY

ADULTS	YOUNG
496.	38733.
750.	2411.
1500.	1259.
2250.	1086.
3000.	1016.

In the printout for example 2, it is impossible to obtain a mean CV of 4% for young by banding only 396 adults. The lowest possible CV for young is 4.43% with only 396 adults banded. The last section of the printout shows

the results obtained by increasing the number of adults banded and computing the corresponding number of young needed to achieve the desired mean CV level for both young and adults. For example, banding 750 adults and 2,411 young would result in a CV of 4% for young and a CV less than or equal to 4% for adults. Other combinations of adults and young could be examined by running BAND2 again with different adult population size increments (e.g., 500 could be used in the input instead of 750).

Example 3: A 5-year study on adult and young Canada geese (Brownie et al. 1985:81–82) has just been completed, and it is decided to continue the study for another 5 years. The survival estimates for the adults were 0.86, 0.76, 0.87, and 0.74; and for young the survival estimates were 0.75, 0.60, 0.78, and 0.80. The adult recovery rate estimates were 0.072, 0.070, 0.065, 0.069, and 0.054. An annual CV of 9% and a mean annual CV of 4% is desired for the next 5 years for the adults, while an annual CV of 12% and a mean annual CV of 6% is desired for the young. The number of adults banded in the first 5 years was 828, 881, 379, 317, and 358; and the number of young banded was 662, 596, 573, 676, and 601. We decide to use the mean annual survival and recovery rate estimates as the anticipated survival and recovery rates for the remaining years of the study. The input file is as follows:

Input file	Remarks
examp3.out	Output data file name
Adult and Young Goose Study, example 3	Title
5	5 years of banding
2	Two age-classes
9,4	Adult annual CV = 9%; mean CV = 4%
12,6	Young annual CV = 12%; mean CV = 6%
1000	Adult population increment = 1,000
y	Y = yes, previous banding data exits
n	N = no, recovery matrix not read from disk
5	*m* = 5 years of previous banding
.86,.76,.87,.74	Four previous adult survival rates
.072,.070,.065,.069,.054	Five previous adult recovery rates
828,881,379,317,358	Number of adults banded, 5 previous years
.75,.60,.78,.80	Four previous young survival rates
662,596,573,676,601	Number of young banded, 5 previous years
y	Y = yes, mean survival rate computed from input
y	Y = yes, mean recovery rate computed from input

and the output is as follows:

Program BAND2—Sample Size Computations for Banding Studies
Patuxent Wildl. Res. Center, USFWS, 5/24/1989

Adult and Young Goose Study, example 3
5 YEARS BANDING, ADULT—CV(ANNUAL SURVIVAL) = 9.0% CV(MEAN SURVIVAL) = 4.0%
YOUNG—CV(ANNUAL SURVIVAL) = 12.0% CV(MEAN SURVIVAL) = 6.0%

	ADULT			YOUNG			
YEAR	SURV RATE	RECV RATE	%CV	SURV RATE	% CV	ADLT BNDS	YNG BNDS
			<<PREVIOUS BANDING DATA>>				
1	0.8600	0.0720	****	0.7500	****	828.	662.
2	0.7600	0.0700	****	0.6000	****	881.	596.
3	0.8700	0.0650	****	0.7800	****	379.	573.
4	0.7400	0.0690	****	0.8000	****	317.	676.
5	0.8075	0.0540	9.0	0.7325	12.0	358.	601.

YEAR	ADULT SURV RATE	ADULT RECV RATE	ADULT %CV	YOUNG SURV RATE	YOUNG % CV	REQUIRED ADLT BNDS	REQUIRED YNG BNDS
			<SAMPLE SIZE RESULTS>				
6	0.8075	0.0660	9.0	0.7325	12.0	1028.	568.
7	0.8075	0.0660	9.0	0.7325	12.0	1259.	719.
8	0.8075	0.0660	9.0	0.7325	12.0	1725.	1032.
9	0.8075	0.0660	9.0	0.7325	12.0	3058.	2014.

*** MEAN ADULT BANDED SAMPLE WAS 134. ***
*** BANDING LESS THAN 200 ANIMALS/YEAR IS NOT RECOMMENDED ***
*** SEE PAGE 186, BROWNIE ET AL. (1985) ***

MEAN	0.8075	0.0660	4.0	0.7325	6.0	200.	766.

SMALLEST POSSIBLE CV(YOUNG) FOR 200. ADULTS = 4.95%
SMALLEST POSSIBLE CV ASSUMES AN INFINITE NUMBER OF YOUNG ARE BANDED
POSSIBLE COMBINATIONS OF ADULTS & YOUNG WITH CV = 4.0% & 6.0%, RESPECTIVELY

ADULTS	YOUNG
250.	498.
1000.	242.
2000.	223.
3000.	218.
4000.	215.

In this case the computed number of adult birds to band was 134, but the message indicates that the minimum the program will allow is 200. Brownie et al. (1985:190) recommend a minimum of 300 birds of each age-class. In this example, it is possible to band enough young to meet the desired CV($\bar{\bar{S}}'$) of 6% with only 200 adults. The stars (***) under %CV indicate that the %CV for the previous banding data is not computed. From the printout of the possible combinations, additional combinations of adults and young could be obtained. The user can look at other possible combinations by running the program again with another adult population size increment besides 1,000.

Example 4: For the last example, the input file described in the Batch Input section is used. The files are from Brownie et al. (1985:58), and are repeated below.

Input file	Remarks
examp4.out	Output data file name
5 additional years of banding based on Brownie et al. 1985:58, example 4	Title (all on one line)
5	5 years of banding
2	Two age-classes
13,3	Adult annual CV = 13%; mean CV = 3%
13,4.5	Young annual CV = 13%; mean CV = 4.5%
1000	Adult population increment = 1,000
y	Y = yes, previous banding data exists
y	Y = yes, recovery matrix to be read from disk
examp4.dat	Recovery matrix input file name
y	Y = yes, mean survival rate computed from input
y	Y = yes, mean recovery rate computed from input

The banding data file "examp4.dat" contains:

```
Adults and Young banded, San Luis Valley, CO 1963-1971
9,9,1963,1
10,13,6,1,1,3,1,2,0
58,21,16,15,13,6,1,1
54,39,23,18,11,10,6
44,21,22,9,9,3
55,39,23,11,12
66,46,29,18
101,59,30
97,22
21
231,649,885,590,943,1077,1250,938,312
83,35,18,16,6,8,5,3,1
103,21,13,11,8,6,6,0
82,36,26,24,15,18,4
153,39,22,21,16,8
109,38,31,15,1
113,64,29,22
124,45,22
95,25
38
962,702,1132,1201,1199,1155,1131,906,353
```

Note: It may be necessary to enter a return character after the last line above by pressing the return or enter key.

The results are shown below.

Program BAND2—Sample Size Computations for Banding Studies
Patuxent Wildl. Res. Center, USFWS, 5/24/1989

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5 Additional Years of Banding Based on Brownie et al. (1985:58), example 4
5 YEARS OF BANDING, ADULT—CV(ANNUAL SURVIVAL) = 13% CV(MEAN SURVIVAL) = 3.0%
YOUNG—CV(ANNUAL SURVIVAL) = 13.0% CV(MEAN SURVIVAL) = 4.5%
RECOVERY MATRIX OF
Adults and Young banded, San Luis Valley, CO 1963-1971

	ADULT			YOUNG			
YEAR	SURV RATE	RECV RATE	% CV	SURV RATE	% CV	ADLT BNDS	YNG BNDS
			<<PREVIOUS BANDING DATA>>				
1	0.5756	0.0433	****	0.4709	****	231.	962.
2	0.6359	0.0856	****	0.5064	****	649.	702.
3	0.6665	0.0590	****	0.5891	****	885.	1132.
4	0.8051	0.0628	****	0.5909	****	590.	1201.
5	0.6496	0.0520	****	0.4776	****	943.	1199.
6	0.5525	0.0633	****	0.6521	****	1077.	1155.
7	0.5719	0.0789	****	0.4635	****	1250.	1131.
8	0.5415	0.0888	****	0.3926	****	938.	906.
9	0.6248	0.0673	13.0	0.5179	13.0	312.	353.

YEAR	ADULT SURV RATE	ADULT RECV RATE	ADULT % CV	YOUNG SURV RATE	YOUNG % CV	REQUIRED ADLT BNDS	REQUIRED YNG BNDS
			<SAMPLE SIZE RESULTS>				
10	0.6248	0.0668	13.0	0.5179	13.0	752.	1253.
11	0.6248	0.0668	13.0	0.5179	13.0	845.	1438.
12	0.6248	0.0668	13.0	0.5179	13.0	1048.	1855.
13	0.6248	0.0668	13.0	0.5179	13.0	1676.	3261.
MEAN	0.6248	0.0668	3.0	0.5179	4.5	209.	2914.

SMALLEST POSSIBLE CV(YOUNG) FOR 209. ADULTS = 3.96%

SMALLEST POSSIBLE CV ASSUMES AN INFINITE NUMBER OF YOUNG ARE BANDED

POSSIBLE COMBINATIONS OF ADULTS & YOUNG WITH CV = 3.0% & 4.5%, RESPECTIVELY

ADULTS	YOUNG
259.	1257.
1000.	455.
2000.	410.
3000.	397.
4000.	390.

In the final example, the investigator would only have to band 209 adults for an additional 5 years to achieve a 3% mean annual CV for adults, while 2,914 young would have to be banded to achieve a 4.5% mean annual CV. The smallest possible CV for young would be 3.96%; this is a theoretical value that assumes an infinite number of young are banded. If an annual CV of 13% is desired for year 12, the investigator would have to band 1,048 adults and 1,855 young for the next 5 years.

Error Condition

An important error condition that will cause program BAND2 to stop is if $f_i > 1 - S_i$ for a new study, or if $\bar{f} > 1 - \bar{S}$ for a new or an ongoing study. In a new study, this results from choosing yearly or average survival and recovery values that are illogical. In an ongoing study this can also result from poor estimates of the yearly survival and recovery rates, S_i and f_i, such that $\bar{S} + \bar{f} > 1.0$. For an ongoing study, the investigator must choose a best guess for the previous yearly survival and recovery rates such that the sum of the average rates, $\bar{S}$ and $\bar{f}$, is not greater than 1. In some instances, the data from an ongoing study (and, consequently, the survival and recovery estimates) may be so poor that sample size must be computed as if a new study is beginning.

Program Details

Program BAND2 will run on an IBM-PC, AT, 80386, or compatible, and most runs only take a few seconds. The program was written in FORTRAN 77, and compiled with the Ryan-McFarland compiler, RMFORT. Program BAND2 consists of a main routine and two subroutines. Currently, 30 years of previous banding can be input, and up to 50 years of proposed banding computed. This can easily be changed by increasing the dimensions of the program. The program should compile using most MS-DOS FORTRAN compilers, including mainframe compilers with few, if any, changes.

If you would like to obtain a copy of the program (including source code and examples), or if you have questions or problems with the program, write to:

Jim Hines or Jim Nichols
U.S. Fish and Wildlife Service
Patuxent Wildlife Research Center
Laurel, Md. 20708

or

Ken Wilson
Colorado Cooperative Fish and Wildlife Research Unit
201 J. V. K. Wagar Building
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Sample sizes necessary for estimating survival rates of banded birds, adults and young, are derived based on specified levels of precision. The banding study can be new or ongoing. The desired coefficient of variation (CV) for annual survival estimates, the CV for mean annual survival estimates, and the length of the study must be specified to compute sample sizes. A computer program is available for computation of the sample sizes, and a description of the input and output is provided.

Key words: Banding, survival rates, sample size, tagging.

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